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SELECTED PROBLEMS OF EVALUATION AND CLASSIFICATION OF HISTORICAL BUILDINGS USING ROUGH SETS

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Abstract. *The paper presents the problems associated with multicriteria evaluation of historic buildings. The capabilities of modeling the monuments in order to use the Rough Sets approach for their evaluation were presented. The problems of selection criteria for the evaluation and taking into account the structure of the object, as well as the problem of discretization and its impact on the generating of the rules were discussed.*

Keywords: heritage preservation, valuation, classification, rough sets

WYBRANE PROBLEMY WARTOŚCIOWANIA I KLASYFIKACJI BUDOWLI ZABYTKOWYCH Z WYKORZYSTANIEM ZBIORÓW PRZYBLIŻONYCH

Streszczenie. *W artykule zaprezentowano problemy związane z wielokryterialną oceną budowli zabytkowych. Przedstawione zostały możliwości modelowania obiektu zabytkowego w celu wykorzystania podejścia Zbiorów Przybliżonych dla ich wartościowania. Omówiono problemy doboru kryteriów oceny oraz uwzględnienia struktury obiektu, jak również problem dyskretyzacji i jego wpływ na generowanie reguł.*

Słowa kluczowe: ochrona dziedzictwa, wartościowanie, klasyfikacja, zbiory przybliżone

Introduction

The twenty-first century poses new challenges in the management of cultural heritage. The challenges arise in many areas, and each of these is a complex issue.

First, the concept of cultural heritage covers a wide spectrum of different objects. An attempt to develop universal solutions in the field of heritage as a whole is highly ambitious. Focusing exclusively on monuments issues we may still encounter very different scientific, technical as well as practical problems.

The monument accordance with the act [21], is called the property or a movable thing, part of them or teams, being the work of man or of his business and forming a testimony of a bygone era or events which preservation is in the public interest due to their historical, artistic or scientific value. Monuments in general can be divided into three groups:

- immovable monuments,
- movable monuments,
- archaeological monuments.

Immovable monuments can be further classified into: cultural landscapes, urban systems, groups of buildings, works of architecture and construction, defensive structures, objects of technology, cemeteries, parks, gardens and other forms of designed green spaces, places commemorating historical events or activities of prominent personalities and institutions.

Special protection should be included into immovable monuments. This is due to the fact that these objects, as opposed to the movable monuments cannot be protected by a fixed protection (placing in the museum, under the roof, etc.). The number of these objects makes the problem of their monitoring and the protection is particularly difficult because it requires the support of modern technologies. In Poland, 70.782 buildings is registered as immovable monuments in the national register of architecture monuments and 5.299 of them belong to the Malopolska province (as of 04.04.2016) [22]. In Krakow, in the district register of architecture monuments there are 6.343 historical monuments, 1.223 of which is placed in the national register of architecture monuments [20]. The total number of immovable monuments in Poland that are not included in the national register of architecture monuments but which are subjected to a conservation area exceeds one million [22].

There is another problem of great dynamism in the area of monuments. This is due to the constant changes of objects. New objects appear in the registers while other objects are removed from them. For example, the state of the national register of architecture monuments to day of 04.10.2010 amounts to 64 673 buildings, 4 948 of which in the Malopolska province alone [22]. As it can be noticed, over 6000 new objects appeared in the registry in less than six years.

The result of so many threats, as well as the effect of the passage of the time and warfare is the general poor state of preservation of the historic substance. Table 2 shows how many monuments require different types of activities [22].

Table 1. Monuments division of work required

Work required	Percent
not require	10%
minor repairs	42%
protection repairs	21%
general renovation	26%

As we can see, nearly the half of monuments in Poland is in the state which needs a large renovation. Due to the large number of objects that require maintenance, as well as many threats and progressive degradation, there is an irreversible annihilation of the heritage and, therefore, actions for their protection are extremely important and urgent. In addition, the national heritage protection planning must take into account the existence of many restrictions. Among the most important restriction there are:

- a limited amount of funds,
- spending time restrictions (e.g. European Union projects),
- limited human resources (specialists in history, architecture, restoration),
- ownership (not every object can be renewed with each type of funding).

Quoting prof. Szmygin we should note that the ongoing changes in the area of conservation encompass the key elements that are determining the system of monument protection [15].

Firstly, the understanding of a monument is changing. The notion of a monument is supplemented/substituted by the considerably broader notion of heritage.

Secondly, the conditions of monument protection are changing. Commercialization, privatization and decentralization of responsibility for protection and financing of monument protection deepen, and that is why the opinions of stakeholders (not of specialists) gain ever more meaning.

Thirdly, the aims of monument protection have changed. In the maintenance of monuments, the aims/values [that may be deemed as] extra-conservational are ever more dominating as are the needs of stakeholders (not of specialists).

Fourthly, the principles and forms of monument protection have changed. What follows is a departure from the notion of equal value of monuments and universalism of principles of conservation, the differentiation of forms of protection and use of monuments deepens [15].

In such a situation, in order to manage human and financial resources properly, it seems necessary to make the classification and scheduling of historic buildings.

1. Valuating of monuments

Valuating of historic buildings should be considered as one of the fundamental problems of modern national heritage protection. There are two basic groups of evaluation purposes – social and practical objectives [14].

Social objectives are identical with the roles performed by the monuments:

- a cultural role,
- an educational role,
- an economical role,
- a role, which aim is to arouse an interest in monuments and thereby increase the effectiveness of protection.

Among practical aims, which are designed for valuation there are:

- building a new quality of basic knowledge about the resources that make up our heritage,
- improving security organization,
- making decisions that are aimed directly at conservation practice.

The studies presented in this article focus on objects such as residential building (houses). It should be noted that the objects in this category have also a commercial aspect. Apart from taking into account the economic role within the social objectives, we must take into consideration that residential buildings are a typical component of the real estate (contrary to, for example, sacred objects that are rarely subjected to such an action). These facilities are also used in service as shops, restaurants, etc. And so they are often rented. Therefore, these objects can be valuated (from purchase or rental point of view). Thus, the valuation of such objects, including the urgency of conservation work and the permissible scope of work to the structure of the monument, gains extra motivation.

Today's economic realities make the peculiar situation of the protection of monuments. It is based on a determination of the objects that should be protected and determining the level of protection. Individual objects have to be assessed. Then, on the basis of this assessment, a decision is made which objects should be subjected to interference, and how big it can be.

According to the research concept of prof. J. Tajchman the valuation resulting from the analysis of the functional and spatial scheme allows the division of objects into three categories [17]:

- objects to the absolute maintenance or restoration,
- objects which allow certain minimum interference,
- objects that can be converted partially or even completely.

The very meaningful problem for the entire heritage protection is the analysis of values. The key task of the contemporary conservation theory is the elaboration of methodology which shall enable the assessment of the value of monuments, while taking into consideration all the essential factors (type of a monument, circumstances of its evaluation, stakeholders etc.). Key meaning of evaluation in the contemporary monument protection results from the following reasons [15]:

- evaluation is the basis of identification of monuments,
- the definition of value is the basis for the differentiation of monuments,
- definition of a monument's value is the basis of justification of monument protection,
- evaluation should be the foundation of defining of principles and forms of protection at the level of given structures.

The evaluation is necessary in every phase of dealing with a monument – it is most likely the most important process in their treatment. It means that the effective monument protection in the 21st century (and the ongoing change of the paradigm of that discipline) is not possible without an adequate methodology/system of evaluation [15].

It is necessary to develop a method that will separate building complexes with different values – from unique to the average, and on such a basis should be determined the policy of conservation. This mode of action is not only necessary for the proper management of a group of monuments, but also for the formation of the current conservation strategies and undertaken practical actions. It should be emphasized that regardless of the number of monuments and their diversity, without adjustment of this type, it is not currently possible to manage the entire historic resource [8].

Thus, for the proper assessment several main aspects should be taken into account.

The first one is the value of given monuments. The issue of valuation of the monument is complex itself, because we can distinguish many types of evaluation, based on the set of different criteria. On the basis of works [1, 13] and [19] we can select the following criteria for evaluation of monuments:

1) Authenticity – the level of preservation of historic substance associated with the period of the first phase and later accretions.
2) Integrity – the level of preserve the style of the original historic buildings, measured by completeness of the work from the point of view of the amount of the preserved legible original fragments.
3) Historical-scientific source – the level of usefulness as a material for research.
4) The historical and emotional thread – the level of the meaning associated with granting to the site important and archaeological meanings in the area of social life.
5) The artistic theme – the level that depends on the quality of the work that is being evaluated under the criteria of the relevant field of art.
6) The aesthetic content – the level of emotional feelings associated with the nature of the aesthetic experience.
7) Usability – the level of the preservation of ancient historical and current utility functions.
8) Uniqueness – the uniqueness of a given object in a given area and / or in relation to the timeline.

An evaluation of monument by historical, scientific and artistic criteria also follows from the Act of 23 July 2003 about the protection of monuments and the care of monuments [7]. Valuation based on the authenticity and integrity meets the additional requirements applicable to the certification of cultural property of UNESCO.

Among another elements, in addition to the value of the object for the sake of the different criteria, there are:

1) The preservation state – defined as the physical state of the object at any given time. Into the model of the monument card designed by the National Heritage Board of Poland in 2011, a column was introduced that indicates the state of preservation, where in a scale of 1–5 should be assessed not only the condition of the technical preservation but also its value – a total of one digit [8]. In our model, an assessment of the value of the monument is intentionally not included in the assessment of its conservation status. Researches among other things are going to allow the assessment of the impact of conservation status (current and future, taking into account the rate of degradation) on the value of the object from the point of view of different criteria.
2) Degradation rate – the progress of processes destructing an object. These processes include both natural degradation connected with the operation of the building, and degradation resulting from poor condition and inadequate security facility. The rate of degradation significantly affects the poor state of the object and vice versa. A high rate of degradation can, at the same time, in a very short time reduce in a very short time the value of objects in certain criteria.

2. Modeling of monuments

Description of the monuments in the form of a model taking into account different criteria values has a purpose to create a system that supports the work of conservators. In addition, such a system would facilitate the management of the national heritage of immense value of material and non–material, and of great complexity due to the diversity of historic structures. Additionally, the approach to the protection of monuments is undergoing continuous transformations. The understanding of the monument as a concept is being changed. It is replaced (extended) through

the concept of heritage. The reality surrounding monuments is being changed through the increased participation of the private sector and thus commercialization. Targets of the protection of monuments are also undergoing changes as well as the forms of that protection.

It should be added that the ongoing transformations have a dynamic character – they happen at all times, reciprocally influencing each other. These changes are not autonomous – they are neither planned nor controlled within the conservation system [15].

The development of the information system taking into account the complexity of the problem and the above-mentioned changes, makes it possible to carry out more effective action in the field of the protection of monuments.

According to the above mentioned categorization of objects, it [17] divides objects into three groups:

- to the absolute maintenance or restoration,
- which allow certain minimum interference,
- that can be converted partially or even completely.

Thus, the first division of monuments is to evaluate the terms of the conservation and construction actions. It depends on both the results of individual valuations based on various criteria and the current state of the object as well as the rate of its degradation.

The second division of the monuments is carried out according to the level of urgency of conservation work. Similarly, as in the case of the first division, this division is also dependent on individual valuations, the current state of the object and the rate of its degradation.

In practice, the greater the value of the monument and the worse state of the preservation, the higher is the urgency of the conservation work. However, with similar values and the state of the preservation (low), the range of an acceptable construction work is greater. Additionally we have to take into account the rate of degradation of the object.

Due to the nature of the issue, we can consider various decisions in relation to the historic building. The same data are important when deciding on various issues. In order to present the concept, two decision classes based on two different divisions of monuments have been shown.

Determining exactly what kind of dependency exists between these data would allow for the creation of rules that would support decision-makers on the monuments. These rules should be general enough to be able to use them to estimate new facilities, which have been registered in the system after the development of rules. On the other hand, these rules should be sufficiently detailed to classify different objects properly. At the same time, a set of rules should be dynamic so that it allows the reconstruction depending on the acquisition of new information on objects already registered in the system, the introduction of new facilities or changes in valuation.

In order to apply the rough set approach to build decision rules relating to historic buildings, information about them should be presented in the form of a decision table.

Taking the above mentioned approaches to the analysis of data on monuments into account, the key issue becomes the answer to the question: at what level of detail shall we describe the monument. The first option is to create a decision table based on a single set of criteria that evaluate and describe the state of preservation and the rate of degradation. This approach simplifies modeling, because we consider only a single value of each attribute for the whole object. In such a scenario, we can determine the following descriptive model $\mathcal{M}(m)$ of a monument $m \in M = \{1, \dots, M\}$ as follows:

$$\mathcal{M}(m) = (W^m, S^m, R^m, D^m)$$

where W^m – a set of evaluative criteria for the given object for the sake of the individual evaluation criteria.

$$W^m = \{w_1^m, \dots, w_k^m, \dots, w_{K(m)}^m\} \subset W, m \in M$$

W – is a collection of all the evaluative criteria for the object included in the system ($W \subset N$).

$K(m)$ – the number of evaluation criteria value of the object. In the presented model, we assume a fixed number of criteria of evaluation value which equals 8.

S^m – value corresponding to the preservation state of the object.

R^m – value corresponding to the rate of degradation of the object.

D^m – a set of values corresponding to the decision attributes.

$$\mathrm{D^m} = \{\mathrm{d_1^m}, \dots, \mathrm{d_p^m}, \dots, \mathrm{d_{P(m)}^m}\} \subset \mathrm{D}, \mathrm{m} \in \mathrm{M}$$

D – is a collection of decision attributes for the object included in the system ($D \subset N$).

$P(m)$ – the number of attributes of the object. In the presented model, we assume a fixed number decision attributes equals 2.

This model has been saved in a table, because for the use of the approach of rough sets the most convenient starting point is the decision table. Table 2 presents a decision table for the above model.

Each attribute from the sets W^m, S^m, R^m has a different weight (significance) in the overall assessment of the heritage site because of its value, state of preservation and the rate of degradation. Because the analysis can be designed both to define the permissible scope of work and urgency of this work, each attribute has two weights, for two different purposes (permissible scope of work – 1 urgency of the work – 2). Let's assume:

$$\alpha^1(\mathrm{w_k^m}) \in [0,1], \mathrm{w_k^m} \in \mathrm{W^m}$$
$$\beta^1(\mathrm{s^m}) \in [0,1], \mathrm{s^m} \in \mathrm{S^m}$$
$$\gamma^1(\mathrm{r^m}) \in [0,1], \mathrm{r^m} \in \mathrm{R^m}$$
$$\alpha^2(\mathrm{w_k^m}) \in [0,1], \mathrm{w_k^m} \in \mathrm{W^m}$$
$$\beta^2(\mathrm{s^m}) \in [0,1], \mathrm{s^m} \in \mathrm{S^m}$$
$$\gamma^2(\mathrm{r^m}) \in [0,1], \mathrm{r^m} \in \mathrm{R^m}$$

This model, however, presents a potential problem of excessive generalization. The fact that the monument is a complex structure is not included in this model. Individual sections may have different state and a different rate of degradation.

The second possibility is the modeling of the monument with regard to its construction. The building consists of parts (elements) that can be distinguished. Each part of the monument can be assessed in terms of the state of preservation and the rate of degradation. For the individual parts of the object state of preservation and the rate of degradation can be different. You can also consider a model that takes into account, for example, only the complexity of the structure in order to evaluate the state of preservation or only the rate of degradation, but the inclusion of these two divisions is justified – there may exist dependencies between them. Taking into account the complex structure of the monument's model $\mathcal{M}(m)$ monument $m \in M = \{1, \dots, M\}$ is as follows:

$$\mathcal{M}(\mathrm{m}) = (\mathrm{W^m}, \mathrm{S^m}, \mathrm{R^m}, \mathrm{D^m})$$

where:

W^m – a set of evaluative criteria for the object because of the individual evaluation criteria.

$$W^m = \{w_1^m, \dots, w_k^m, \dots, w_{K(m)}^m\} \subset W, m \in M$$

W – is a collection of all the evaluative criteria for the object included in the system ($W \subset N$).

$K(m)$ – the number of criteria of evaluation value of the object. In the presented model, we assume a fixed number of criteria of evaluation value, which equals 8.

S^m – a set of values corresponding to the assessments concerning the state of preservation of the individual elements of the object.

$$\mathrm{S^m} = \{\mathrm{s_1^m}, \dots, \mathrm{s_l^m}, \dots, \mathrm{s_{L(m)}^m}\} \subset \mathrm{S}, \mathrm{m} \in \mathrm{M}$$

S – is a set of numbers concerning all assessments of the preservation state of individual components of the object included in the system ($S \subset N$).

$L(m)$ – the number of the components of the object. In the presented model we assume a constant number of components which equals 7.

R^m – a set of values corresponding to the assessments describing the rate of degradation of individual elements of the object.

$$\mathrm{R^m} = \{\mathrm{r_1^m}, \dots, \mathrm{r_l^m}, \dots, \mathrm{r_{L(m)}^m}\} \subset \mathrm{R}, \mathrm{m} \in \mathrm{M}$$

R – is a set of numbers of all evaluations describing the rate of degradation of the individual components of the object included in the system ($R \subset N$).

$L(m)$ – the number of the components of the object. In the presented model we assume a constant number of components which equals 7.

D^m – a set of values corresponding to the decision attributes.

$$D^m = \{d_1^m, \dots, d_p^m, \dots, d_{P(m)}^m\} \subset D, m \in M$$

D – is a collection of decision attributes for the object included in the system ($D \subset N$).

$P(m)$ – the number of attributes of the object. In the presented model, we assume a fixed number decision attributes which equals 2.

As in the previous model, also in this one attributes have weights. They are determined for two different purposes: permissible scope of work – 1 and urgency of the work – 2. Let's assume:

$$\alpha^1(w_k^m) \in [0,1], w_k^m \in W^m$$
$$\beta^1(s_l^m) \in [0,1], s_l^m \in S^m$$
$$\gamma^1(r_l^m) \in [0,1], r_l^m \in R^m$$
$$\alpha^2(\mathrm{w_k^m}) \in [0,1], \mathrm{w_k^m} \in \mathrm{W^m}$$
$$\beta^2(s_l^m) \in [0,1], s_l^m \in S^m$$
$$\gamma^2(r_l^m) \in [0,1], r_l^m \in R^m$$

Also this model, in order to analysis by rough sets, should be saved in the form of a decision table. A part of the sample table for this model is shown in table 3.

Another very important issue is the way of expressing the values describing various attributes. In practice, restorers and historians use natural language to express the state of preservation of the object. The description of behavior can affect various parts of the object or its entirety. For example, an object can have a condition: very good, good, satisfactory, etc. There are also descriptions of the objects in which the conservation status is expressed in a percentage (0–100%).

Even greater difficulties are related to the description of the object for different evaluative criteria. In the monument record card there are typically used longer or shorter descriptions that mention valuable elements of the object owing to the different criteria.

In order to use the decision tables and determinate the rules, it is necessary to apply uniform description dictionaries of all the objects from the point of view of each attribute. In this work it is assumed that all the attributes that describe the value of the object, its state of preservation and the rate of degradation will be expressed by integers from the range 1–5. For the coefficients of the conservation status and the rate of degradation a similar approach was applied. The individual numbers will correspond to the words from the dictionary – table 4.

However, for decision attributes: permissible scope of work and urgency of the work, integers from 1–3 have been used. For the attribute permissible scope of work, these values have been adopted in accordance with three possible classification by prof. Tajchman [17]. Dictionaries have been shown in table 5.

In the model of the monument, we can also take into account other (additional) aspects. An important role in the evaluation of the historical object plays not only the preservation state of the object and its rate of degradation, but also a set of factors threatening the monument. For each monument the set of threats will be different. This is due to the fact that the objects are located in different places or they are made of various materials, etc. Thus, it is possible to consider both the impact of these factors on the object and its various components (structural elements).

Criteria for the monument value, are considered in the model presented in the paper, relative to the entire object, but can also be considered in relation to its individual components (elements of the structure). Not for all the criteria, there is a possibility to examine them in terms of elements of the object. The criterion of the integrity applies to the object as a whole (not individual elements). However, other criteria may be considered for selected elements of monuments separately.

The reason why these additional elements have not been included in the actually considered model is not the problem of the excessive complexity of the model. The problem is to obtain sufficient quantities of reliable and current information on such specific topics as the value of each evaluative criteria for the individual structural elements of the object. A precise description of the various physical and chemical factors threatening an object (and more specifically: its individual structural elements) requires additional data sources. It would be necessary to obtain some information from the experts in the field of environmental monitoring, chemistry, construction, etc.

Both of the above-mentioned aspects will be dealt with subsequently. From the point of view of the development of a monument classification model, the addition of further components is not a problem. The model is flexible, and its structure is dynamic as well as the content.

Table 2. Decision table for the first model

Basic information			Criteria of evaluation											
Monument id	Name	Address	Authenticity	Integrity	Historical-scientific	historical and emotional	Artistic	Aesthetic	Usability	Uniqueness	Preservation state	Degradation rate	Permissible scope of work	Urgency of the work
1	Building X	A Str. 1	3	4	2	1	3	1	4	2	4	2	1	1
2	Building Y	B Str. 7	4	4	3	2	3	3	2	4	3	2	2	3
3	Building Z	C Str. 3	5	5	5	4	4	3	2	3	5	3	3	2

Table 3. Decision table for the second model (a fragment)

Basic information			Criteria of evaluation			Preservation state			Degradation rate			Permissible scope of work	Urgency of the work
Monument id	Name	Address	Authenticity	Integrity	. . .	Foundations	Basement	. . .	Foundations	Basement	. . .		
1	Building X	A Str. 1	3	4		4	3		1	1		1	1
2	Building Y	B Str. 7	4	4		3	2		3	2		2	3
3	Building Z	C Str. 3	5	5		5	5		2	2		3	2

Table 4. Dictionaries for attributes: evaluation, preservation states and degradation

DICTIONARIES				
Authenticity	Integrity	Historical-scientific	. . .	Preservation state	Degradation rate
1 = very low	1 = very low	1 = very low		1 = very low	1 = very low
2 = low	2 = low	2 = low		2 = low	2 = low
3 = medium	3 = medium	3 = medium		3 = medium	3 = medium
4 = high	4 = high	4 = high		4 = high	4 = high
5 = very high	5 = very high	5 = very high		5 = very high	5 = very high

Table 5. Dictionaries for decision attributes

DICTIONARIES	
Permissible scope of work	Urgency of the work
1 = objects can be converted partially or even completely	1 = low
2 = objects which allow certain minimum interference	2 = medium
3 = objects to the absolute maintenance or restoration	3 = high

3. Multicriteria classification and Rough Sets

In decision problems related to the reuse of historical assets conflicts can arise and the availability of analytical frameworks able to support the process is getting more and more important. It has been generally agreed that Multicriteria Decision Analysis (MCDA) can offer a formal methodology to deal with such decision problems, taking into account the available technical information and stakeholders' values [4]. Researches in this area are taken in many countries [9, 18].

In Poland, the creation of the new heritage preservation system is based on privatization of ownership, responsibility and financing of monuments. Low quality of any of the system elements or lack of cohesion between them results in dysfunction of a given heritage preservation system. In Poland (and other post-communist countries) the transformation continues – a new heritage protection system has not yet been fully developed [16]. An important element of the system should be a tool to multicriteria evaluation of monuments.

The rough set theory is founded on the assumption that we associate some information (data, knowledge) with every object of the universe of discourse. Objects characterized by the same information are indiscernible (similar) in view of the available information about them. The indiscernibility relation generated in this way is the mathematical basis of rough set theory [11, 12]. In [2] the implementation of such an approach was presented.

In rough sets theory, data can be shown as a decision table in which rows represent objects, and columns represent attributes of these objects. Some of these attributes make the set of decision attributes (represented by D) while the rest make the set of conditional attributes (represented by C). Formally, the decision table is given as an ordered 5-tuple [2]:

$$DT=(U,C,D,V,f)$$

where: $C, D \subset A; C \neq \emptyset, D \neq \emptyset; C \cup D = A; C \cap D = \emptyset$.

U is a non-empty finite set of objects called the universe of the decision table. f is called the decision function.

$V = \bigcup_{a \in A} V_a$, V_a is called the value set of a∈A.

Thanks to the Rough Sets approach, we can get a set of rules that allows the classification of the new objects relative to a specific criterion. In order to build a classifier, enough data should be collected, with relation to which we know the decision. In this way, we enable the learning process followed by the process of testing the classifier. Testing is performed on the data with relation to which the decision is known as well. Through the process of testing, we can evaluate the effectiveness of the classifier. Created classifier has the possibility to classify the new objects with regard to which the value of the decision attribute is still unknown. The construction of the classifier based on Rough Sets approach reduces unnecessary (overly detailed) rules, the number of which for a large data set (monuments and attributes) could be very large.

At the example of the data in table 6, we can generate a set of 7 rules. However, for decision tables with thousands of objects, there would also be thousands of such rules. Based on the concept of Rough Set theory, core and relative reduct [11], we can reduce the number of rules and simplify them. For example, for data in table 2, the rules may be:

Rule 1 : IF A = 3 AND PS = 3 THEN UoW = 2
Rule 2 : IF A = 5 THEN UoW = 3
Rule 3 : IF A = 4 THEN UoW = 3
Rule 4 : IF A = 3 AND PS = 2 THEN UoW = 1 OR UoW = 2
Rule 5 : IF A = 3 AND PS = 4 THEN UoW = 1

The solution of the problem of too many rules and their excessive complexity (excessive length) does not remove all the difficulties. Thanks to the approach of Rough Sets, inconsistency in data is detected (rule no. 4), but this inconsistency still remains a problem. In cases of monuments for which the assessment of authenticity is 3 and the assessment of the conservation status is 2, we can not clearly determine whether the urgency of the work should be 1 or 2. The solution to this problem would be more detailed assessment – allowing more levels of evaluation than 5. However, taking into account more levels of ratings for each attribute, a problem arises of too detailed rules because they will be created for many combinations of values. In summary, the classic approach of Rough Sets solves only a part of the problem, some are still unsettled.

From the multicriteria sorting point of view, the original rough set approach proved to be insufficient. The original rough set approach cannot extract all the essential knowledge contained in the decision table of multicriteria sorting problem, i.e. problems of assigning a set of objects described by a set of criteria to one of pre-defined and preference-ordered categories [6]. The case of monuments assessment with a number of criteria is a situation in which we must take into account ordinal properties of such criteria. In this case, the indiscernibility or similarity relations have specific nature and the rough set approach is not able to handle correctly such a kind of characteristic. If there is at least one criterion in the decision table, nontraditional solution is needed. The new rough set approach was proposed by Greco in [5] to evaluation of bankruptcy risk. The same solution could be applied for monuments evaluation in heritage preservation, because there are many attributes with preference-ordered categories.

The use of the modified approach makes it possible to detect inconsistencies on the level of ordering. The problem is shown in table 6 on the example of objects No. 2 and 7. For these two objects, we can notice that although unequivocal rules have been generated (1 and 5), an inconsistency exists. This inconsistency cannot be detected by the original Rough Sets approach, whereas the modified approach (taking into account the dominance relation) considers building No. 7 as "better" (more valuable – has at least the same or higher values of criteria) than object No. 1. In such a situation, the lower value of the decision attribute is unjustified.

Table 6. An example of a decision table

Object id	Authenticity (A)	Integrity (I)	Preservation state (PS)	Urgency of the work (UoW)
1	3	3	2	1
2	3	4	3	2
3	5	5	5	3
4	5	4	3	3
5	4	4	3	3
6	3	3	2	2
7	3	4	4	1

The modified approach to the rough sets (dominance-based rough set approach) has further advantages. First, by using the dominance relation instead of indiscernibility relation, it allows a significant reduction in the number of rules [3]. In the example above rule No. 2 is unnecessary (redundant) because rule No. 3 is more general – it is enough that the object has a value of the authenticity criterion equal 4 and the decision attribute has a value equal 3. In addition, the dominance relation allows the use of more levels of evaluation, reducing the importance of data discretization. As a result, we can reduce the occurrence of the problem of conflicting rules, the presence of which is often a consequence of using discretization causing the appearance of objects with the same values of conditional criteria with different value of decision attribute.

Generating rules for the whole decision table can be experimentally compared with the approach, based on the division of a set of attributes / criteria into the groups. As shown in Fig. 1, it is possible to choose a separate groups of criteria, eg. assessment of the evaluation, state of preservation, the rate of degradation and determine the decision rules separately. In cases where the specific rules for a particular object are conflicting, it is possible to assign weights to the groups of attributes.

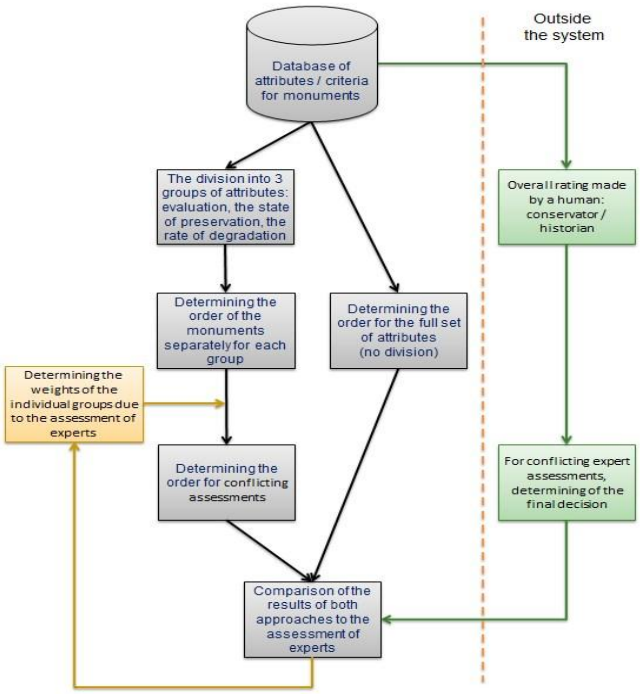

Fig. 1. The division of criteria

4. Conclusions and further works

Modeling of historical monuments, in order to assess and evaluate them, requires consideration of many factors. As shown in the paper, a preparation of the tools to the multicriteria evaluation of monuments is an important issue. It requires the development of appropriate data structures and the use of machine learning approaches. Determining which attributes / criteria are relevant and whether there will be dependencies between them, will be the object of further works. These works will also be carried out in the direction of inclusion in the model of the monument factors threatening objects (physical, chemical, etc.). In addition, the study will take into account time dependencies, ie. the variability of each value assessment attribute, the state of degradation and threats with the passing of time.

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